"GENERAL MOTORS HYBRID PROPULSION SYSTEMS DEVELOPMENT PROGRAM"

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Presentation Outline

The Purpose of the Program:

- To design, build, develop and demonstrate a "production-feasible" electric hybrid propulsion system that
  - -integrates with appropriate vehicle auxiliaries
  - -packages and performs beyond expectations
  - -meets or exceeds all applicable safety standards
  - -is familiar to maintain and operate
  - -provides more overall "features" and "value" to the customer than today's conventional powertrain
- and will increase fuel economy up to two times that of today's vehicle while producing less than ULEV emissions

At the end of first year of our Program we told you the following.

- A series configuration propulsion system was GM's choice due to its ability to deliver both high fuel economy and very low emissions
- The high-level vehicle technical specifications or vehicle-level imperatives were defined and are shown on the accompanying "spider chart" (Attachment 1) .

At last year's Customers' Coordination Meeting (CCM), the end of the second year of our Program, we told you the following.

- The choice for Hybrid Power Unit (HPU) engine had been narrowed to two--Gas turbine and Stirling
- The choice for electro-chemical energy storage had been narrowed to two--spiral wound and bi-polar lead acid batteries
- The choice for the electric drive had been narrowed to technologies similar to those used in the GM Impact EV (now called EV1)--AC induction drive motor and IGBT-based inverter
- All components for the propulsion system had been designed and were being fabricated
- The Gen 1-1 System Mule Vehicle (SMV) was being readied for installation of the first propulsion system which included the gas turbine HPU

At this CCM, as a result of work during the past year of the Program, we are going to tell about some of the details surrounding the following.

- The choice for HPU's has been narrowed to one--the Stirling engine HPU
- The choice for energy storage has been narrowed to one-- a custom-designed spiral wound lead-acid battery

- The Gen1-1 (w/gas turbine HPU) and Gen 1-2 (w/Stirling HPU) SMVs were assembled and are undergoing test and development
- The as yet unproven reliability and high cost (component piece and investment) are still major challenges to making our electric hybrid propulsion system production-feasible (defined to be "technically feasible and commercially viable")

To be more specific about work in the past year, the Program transitioned from "System Design" into "System Development and Validation", with the major deliverables as shown in the Program Master Timing Schedule (Attachment 2). The Program continues to be organized around and work accomplished on the tasks listed in the Program Work Breakdown Structure (Attachment 3). The Program Partners Chart lists what partners are assisting GM with what tasks (Attachment 4).

In May of this year, the Stirling engine HPU from Program partner Stirling Thermal Motors was selected as our Program's HPU of choice.

- Relative to the gas turbine engine HPU alternative, it was projected to have, by the end of the Program, higher overall efficiency and significantly lower cost and noise
- The accompanying spider chart (Attachment 5) shows that the Stirling engine HPU is projected to come close to meeting our Program's HPU Imperatives, especially in the more important criteria of net thermal efficiency at the 1/3 power point, cost and noise.

A custom-designed, spiral wound lead-acid battery from Program partner Optima Advanced Technologies, with improvements made during the past year to specific power, energy density and charge acceptance, is allowing the battery pack system to approach the Program's imperatives shown on the accompanying spider chart (Attachment 6).

- Power improvements were made through an improved post design
- Energy density is being improved by special additives supplied by Optima's subcontractor Arias Research Associates
- Charge acceptance was also found to be influenced by paste additives, but is also a strong function of state-of-charge and temperature
- While a small sample of some battery modules have obtained very high mileage on our Hybrid Electric Vehicle(HEV) driving cycle, battery pack cycle life remains largely unknown and a major challenge

During this past year, both the Gen 1-1 (gas turbine HPU) and Gen 1-2 (Stirling HPU) SMVs were assembled and are now undergoing test and development.

- Both vehicles are identical Chevrolet Lumina Sedans with all propulsion system components mounted so as to have the minimum impact possible on customer seating comfort and luggage capacity
- The Gen 1-1 battery pack sits on top of the existing mid-car tunnel and loads through the truck. The Gen 1-2 battery pack loads from the vehicle bottom into a custom-built mid-car tunnel structure

- The HPU, Electric Drive Unit(EDU) and Power Electronics Bay(PEB) are mounted to the conventional powertrain cradle which is then bottom loaded into the engine bay like a conventional powertrain
- All propulsion system auxiliaries and electric accessories are also mounted in the engine bay

Since assembly, the Gen 1-1 SMV has been used mainly for electric drive and accessories development due to limited operation of the gas turbine HPU. The Gen 1-2 SMV has been only operational as an HEV for about six weeks and performance testing is incomplete. From data collected to date from operation of the SMVs, as well as from component tests before installation in the vehicle, the current performance relative to Vehicle-Level Imperatives can be predicted and is shown on the accompanying spider chart (Attachment 7).

While it appears that the Program is demonstrating good "technical feasibility" of this electric hybrid propulsion system, especially with respect to performance imperatives, there are at least two very major customer-driven imperatives that are not being met--reliability and cost.

- Projected overall reliability is well below the Program's imperative, mainly due to a lack of operating experience and development time
- The projected propulsion system cost is still well above the level at which a positive business case can be made

Tackling these two very major issues through extensive development testing and DFM/A workshops will be the focus of the last two years of the Program.

GM continues to express its appreciation to the U.S. Department of Energy for its encouragement and co-funding of this very important program and to the MRI/NREL for excellence in Program technical and administrative guidance.